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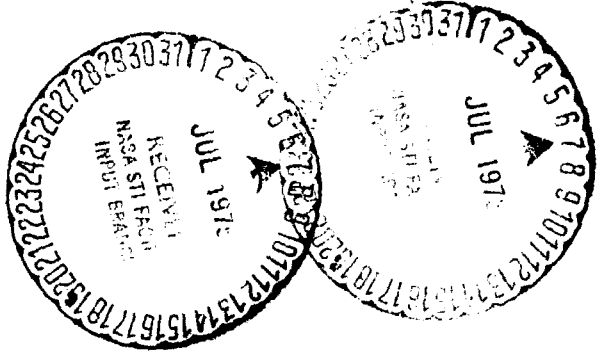
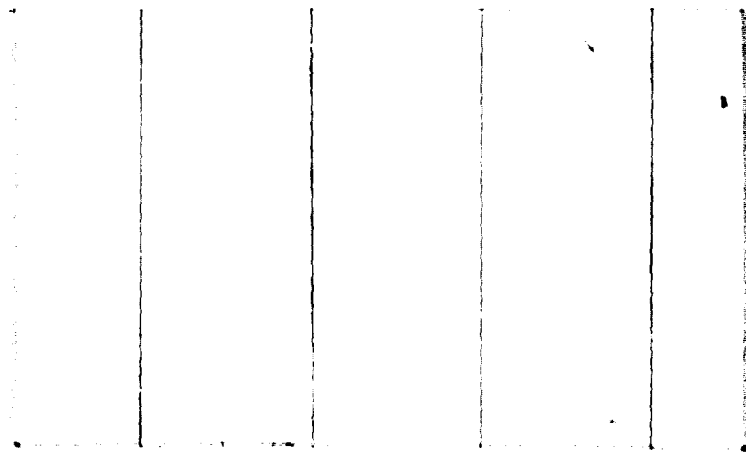
MATHEMATICA INC.

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EXECUTIVE SUMMARY

QUANTIFYING THE BENEFITS TO THE
NATIONAL ECONOMY FROM SECONDARY
APPLICATIONS OF NASA
TECHNOLOGY

Prepared for:

The National Aeronautics and Space Administration
Washington, D. C. 20546

In response to Contract No. NASW-2734

by:

MATHEMATICA, Inc.

P. O. Box 2392

Princeton, New Jersey 08540

June 30, 1975

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A. INTRODUCTION

In the 1958 law establishing the National Aeronautics and Space Administration, Congress charged NASA with conducting its research activities "so as to contribute ... to the expansion of human knowledge of phenomena in the atmosphere and space." Recognizing that such knowledge, like much of the knowledge generated by research, could also have potential applicability in non-aerospace sectors of the economy, Congress further directed NASA to "provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

NASA's success in accomplishing its aerospace objectives is unquestioned. The achievements of the satellite programs, manned space flights, and exploration of the moon are dramatic and well-known. Less clear, however, is the extent to which the knowledge developed in the NASA programs has been useful outside its originally intended aeronautical and space applications. While literally hundreds of instances of non-aerospace applications, ranging from the cardiac pacemaker to gas turbines, have been cataloged, hardly anything is known of the quantitative economic significance of NASA's contributions.

The purpose of this study was to develop preliminary estimates of the economic benefits to the U.S. economy from secondary applications of "NASA technology." If technology is defined as the body of knowledge

concerning how society's resources can be combined to yield economic goods and services, then NASA technology represents NASA's contribution to this body of technical knowledge. Secondary applications refer to uses of NASA generated knowledge for purposes other than those primary mission-oriented ones for which the original R&D was done. These applications occur whenever a non-NASA entity, with or without encouragement from NASA, uses this knowledge in some economic activity.

B. MEASUREMENT APPROACH

The development of procedures to quantify the economic benefits of secondary applications involved the adoption of concepts and tools that are theoretically sound and yet practically useful in dealing with a wide variety of applications of NASA technology. There are two key foundational elements of the approach: one, an understanding of how technological change generates economic benefits; and two, a determination of the role that NASA can play in the process of technological change.

1. The Economic Benefits of Technological Change

In broad terms, the economic process involves the conversion of society's stock of resources into goods and services and the sale or exchange of these goods and services in the marketplace. This activity generates economic benefits by allowing people to consume desired combinations of goods and services. Advancing technology increases these benefits by allowing society to get more from the same stock of resources.

The specific methods for quantifying economic benefits have been the subject of much discussion in the economics literature. The most widely accepted principle for evaluating economic benefits is founded on individuals' "willingness to pay" to move from a "less" to a "more" preferred state. What this principle translates into for the purposes here is that the benefits of technological change can be measured as the cost savings generated by new or improved production processes plus the extra value that consumers attach to new or improved final products. Therefore, by determining how cost and demand for various products are affected by specific technological advances, one can estimate the benefits of these advances.

2. The Benefits Due to NASA

The research process by which technological advances are generated typically involves a complex interaction of various groups and individuals. In solving the particular problems associated with an advance, the individual research "actors" build on or combine their results with those generated by others. As a result, any "credit" for the benefits created by a particular advance should, in a real sense, be shared by the various contributors.

The goal here, of course, is to assign a particular share to NASA in some specific cases. The method for assigning this share is based on the premise that NASA R&D led to an earlier realization

of the particular technological advances being considered. In other words, had NASA not done its R&D -- and had its failure to do so not led to changes in R&D by others -- these technological advances would indeed have occurred, but at a later date.

If one accepts this view of technological advance -- and it has been proposed and defended by a number of authors -- then the measurement of benefits attributable to NASA becomes, at least theoretically, a rather straightforward task. These benefits can be measured as the difference between the present value of two benefits streams: one, the stream resulting from the advance as it has occurred, and two, the stream that would have resulted had NASA not been involved.

In each of the specific cases technical experts outside the NASA establishment were questioned about the speed-up resulting from NASA's role. Of course, there was some variation in their judgment. In order to allow for the inherent uncertainty in this aspect of the study, calculations were made based on alternative assumptions concerning the extent to which NASA accelerated the time stream of benefits. More specifically, benefits were calculated based on a minimum, a maximum, and a conservative "probable" speed-up due to NASA.

C. RESULTS OF CASE STUDIES

Before describing the results of the analysis, three points are worthy of mention. First, the case studies are by no means

a random selection from the possible cases which might have been examined. Cases were deliberately selected where data were available, where NASA's role was widely acknowledged, and where benefits were anticipated to be relatively large. Consequently, until additional experience with more case studies is acquired, it is not possible to draw inferences regarding the total secondary benefits of NASA's R&D. Second, because the case selection was not random and because of the innovative nature of the work, an effort was made to be conservative in the calculations. Third, the brief discussion of the cases which follows is not sufficient for a full understanding of the qualifications and limitations of the analyses. To acquire a more complete comprehension of these, a careful reading of the technical report is required.

1. Cryogenic Multilayer Insulation Materials

NASA's role in cryogenic technology is an outgrowth of the effort to minimize the weight, volume, and evaporative loss of gases used in launch and flight propulsion systems, life support systems, and power generation on board spacecraft. An integral part of this general concern was the design of improved insulation systems. The development of cryogenic insulation technology has contributed substantially to the rapid growth of the cryogenics industry.

In this case study, benefits are calculated as the cost savings generated by the use of multilayer insulation instead of the next best

insulation material (perlite) in the transport of liquid hydrogen, liquid helium, and liquid nitrogen. It should be emphasized that other savings arise from the use of multilayer insulation with liquid hydrogen, helium, and nitrogen, insofar as it is used to insulate storage tanks, piping and other equipment used in the production of these liquid gases.

The two principal sources of measured cost savings due to multilayer insulation are: reduced boil-off loss during the time the cryogen is transported, and reduced transportation costs due to the lighter weight of multilayer insulated tanks. Benefits were estimated using an engineering approach to specify the relevant technical relationships between evaporation loss, weight, and insulation characteristics. The "best guess" or "probable" estimate of benefits is \$1,054 million.

2. Integrated Circuits

Prior to 1960, conventional electronic circuitry was based on the assembly of individually-encapsulated circuit components such as transistors, resistors, capacitors, and diodes. Integrated circuit technology -- the combination of these circuit functions on an inseparable, continuous base--provides significant advantages over conventional circuit technology, particularly in smaller size, lower power consumption, increased speed of operation, improved reliability, and reduced cost per electronic function. These features make integrated circuits especially attractive for space applications.

The introduction of integrated circuit technology produced significant changes in all electronic products, including consumer electronic products, and the estimates of the total benefits to advancing integrated circuit technology reflect its very widespread applicability.

Based on a simultaneous equation estimation of the demand for integrated circuits, estimates of benefits were derived. The "probable" estimate is \$5,080 million.

3. Gas Turbines in Electric Power Generation

Since the early 1940's NASA (then NACA) has been intimately involved in gas turbine technology, primarily as it relates to improvement of jet engines for military and commercial aircraft. This basic research has also produced benefits in the production of electric power, as gas turbines have become more widely used as sources of peaking power and standby capacity.

The use of gas turbines in electric power generation undoubtedly confers many social benefits; e.g., gas turbines are relatively "clean" from an environmental point of view and also enhance the reliability of power production. Nevertheless, the estimates of benefits are based only on the fuel cost savings in power production produced by improvements in gas turbine performance. Improvements in gas turbine performance are assumed to result from advances in turbine technology; gas turbine vintage was used as a proxy for technology level in these calculations. Using standard regression analysis, the relationship between gas turbine vintage and the average cost of fuel consumed in the production of power was estimated; based on this relationship, a "probable" estimate of the total fuel cost savings of \$111 million was determined.

4. NASTRAN

NASTRAN (NASA Structural Analysis) is a general purpose finite element computer software package for static and dynamic analysis of the behavior of elastic structures. Industrial users are generally product engineers in mechanical or civil engineering applications such as aircraft and automobile production, bridge construction, or power plant modeling.

NASA's Goddard Space Flight Center developed NASTRAN, through a combination of in-house and contracted research, over the period 1965 to 1970. It represented substantial improvement over similar extant programs, and was released to public users in November of 1970.

Because few published data exist regarding the extent of use of NASTRAN, estimates of cost savings from the use of NASTRAN were obtained from telephone interviews with a sample of users. From the sample responses the "probable" benefits accruing to the population of NASTRAN users were estimated at \$701 million.

D. SUMMARY AND CONCLUSIONS

A summary of the "probable" estimates for each case study is presented in Table 1. It indicates that total benefits due to NASA for the four cases studied are probably on the order of \$7,000 million.

Table 1

Results of Benefits Estimation

Technology	Interval of Benefits Estimation	Estimated Probable NASA Acceleration (Years)	Probable Benefits Attributable to NASA (Millions)
Gas Turbines	1969 - 1982	1.0	\$ 111
Cryogenics	1960 - 1983	5.0	\$1,054
Integrated Circuits	1963 - 1982	2.0	\$5,080
NASTRAN	1971 - 1984	4.0	\$ 701
Total	—	—	\$6,946

In interpreting the results of this study one should recognize that it is one of the first of its kind ever attempted. The results, while arrived at through careful and rigorous techniques, are sensitive to data uncertainties and analytical simplifications. Though one must necessarily view such results with caution, it seems that the following general observations could be safely made:

- Operational methods can be developed for estimating the secondary benefits of mission oriented R&D.
- Secondary benefits attributable to NASA's R & D programs may be impressively large. For example, the \$7,000 million total for the four cases studied is more than twice NASA's present yearly budget.
- Because secondary benefits may indeed be significant, public decisions concerning the allocation of resources to research and development programs should, where possible, consider such benefits.